Computer Vision Methods for Centerline Extraction

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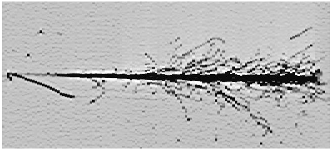
- Computer vision is a field in computer science that seeking methods of extracting information from images and video
  - Developed algorithms for several tasks such as object recognition (e.g. face recognition), shape/feature detection (e.g. blob detection for finger presses on a multitouch panel, feature detection to stich together panoramas), scene reconstruction (i.e. reconstruction of a 3d model of a scene from 2d pictures), motion tracking (e.g. tracking a person walking through a scene)
  - Generally seeks to replicate the visual processing capabalities of humans
- LArTPCs produce images of particle tracks; we keep saying that we can “see” a shower or “see” a track, so why not take a look to see if this field has anything to offer?

Skeleton

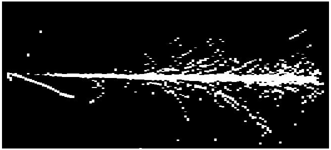
The *skeleton* of a shape is a maximally thin representation of that shape which is equidistant from the shape's boundaries, also known as a symmetry axis since each point on the skeleton is equidistant from at least two points on the boundary

Skeletonization via Morphological Thinning

- Next few methods I describe require a binary image, here a global threshold is applied to an example event determined by Otsu's method (minimizes the intracluster variance above and below the threshold)



$\Longrightarrow$



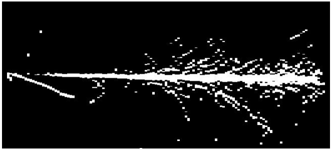
- The hit-or-miss transform tests whether the neighborhood of each pixel in an image matches a certain pattern, called the structuring element; if it does, the pixel is kept, otherwise it is dropped
- Morphological thinning involves removing all pixels which do not affect the connectedness of a shape, which can be determined locally

Skeletonization via Morphological Thinning

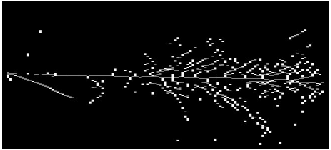
- Structuring elements used for thinning are

$$\left\{ \begin{array}{|c|c|c|}\hline -1 & -1 & -1 \\ \hline 0 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline \end{array}, \begin{array}{|c|c|c|}\hline 0 & -1 & -1 \\ \hline 1 & 1 & -1 \\ \hline 0 & 1 & 0 \\ \hline \end{array}, \text{and rotations} \right\}$$

- 1 indicates a foreground pixel, -1 background, and 0 either
- Repeatedly applying the thinning operation until there is no change yields a skeleton



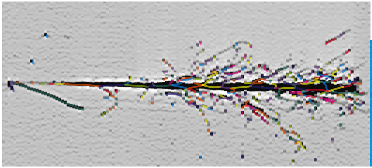
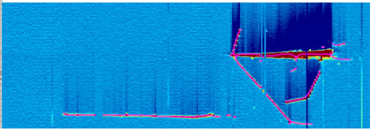
$\Longrightarrow$



- Since the skeleton is maximally thin (1 pixel wide), only pixels at points where tracks meet will have more than 2 neighboring foreground pixels; the skeleton can be split up into collections of 1 pixel wide segments with no intersections that can then be approximated via whatever paramaterized curve, e.g. piecewise linear curve, Bezier spline, etc.

Skeletonization via Morphological Thinning

- Result with Bezier splines:

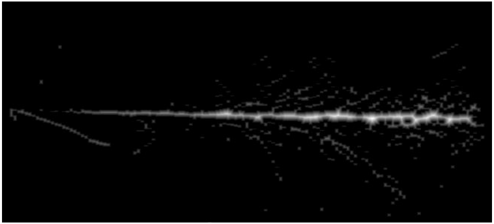
- Performs well enough on thin tracks
- Skeletonization by morhpological thinning is very sensitive to defects in the surface, creates a spurs that need to be pruned in thick regions and is not necessarily medial.
    - Most modern skeletonization algorithms involving morphological thinning also have additional algorithms to select the most topologically significant segments, *e.g.* C. K. Lee, *et al.*, A fuzzy approach to determine morphological thinning algorithms for fast removal of unwanted skeletal legs, Engineering Applications of Artificial Intelligence, Volume 8, Issue 3, June 1995, Pages 281-298

Distance Transform

Distance Transform

The distance transform, $D(x)$, of a binary image is the minimum distance from the point x to a pixel in some subset of the image, usually the background.

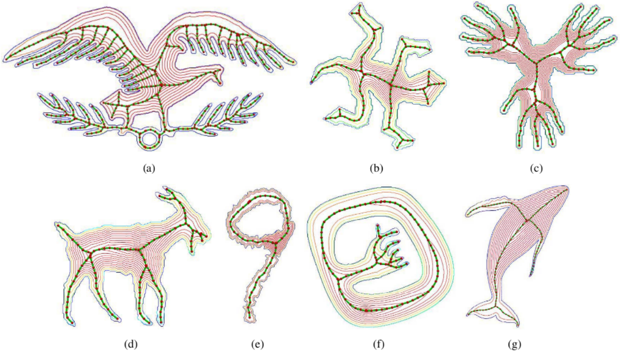
- The distance transform of the binary event image:



Interface Evolution

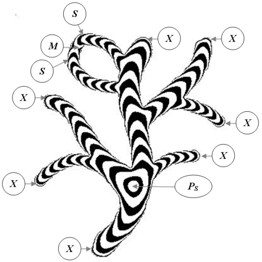
- Suppose we have a simple closed curve $\gamma(s)$ in $\mathbb{R}^2$ that is propagating normal to itself in time. If the speed of propagation doesn't change sign, then the curve at at a time t is the level set of the arrival-time function $T(x, y)$ defined as the time the curve reaches a point (x, y). If the speed of the wave is soley dependent on it's position, then the $T(x, y)$ satisfies the Eikonal equation, $|\nabla T| = 1/F$. This equation can be solved efficiently using fast marching methods; see J. Sethian. Level Sets Methods and Fast Marching Methods. Cambridge University Press, 2nd edition, 1999.

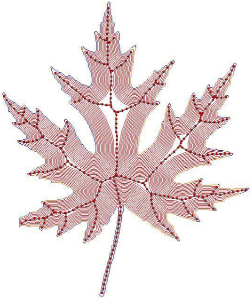
Centerline Extraction from Level Sets



- M. S. Hassouna, *et al.*. 2005. Robust Centerline Extraction Framework Using Level Sets. In Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (Cvpr'05)

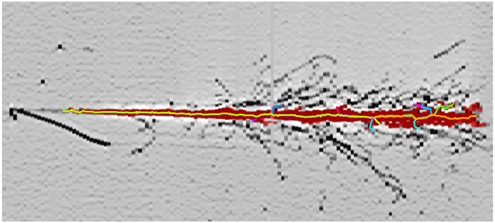
Centerline Extraction from Level Sets





1. Compute distance transform D and find the most medial point, P_s
2. Propagate a slow wave, T_1, from P_s with the speed given by D^β for some $0 \leq \beta \leq 1$
3. Find level sets of T_1, level sets which are maximal among their connected neighbors are topologically significant
4. Compute a fast wave, T_2, from P_s with the speed given by $e^{\alpha D}$ for some α
5. Backsolve curves from topologically significant points found from T_1 along the gradient of T_2 back to P_s

Centerline Extraction from Level Sets

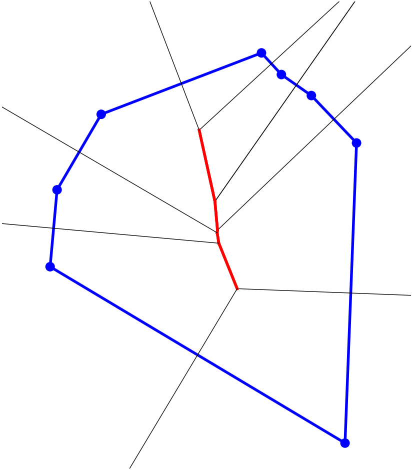


- Level set method performed on highlighted cluster in sample event
- Performs arguably better than skeletonization by morphological thinning
- Current Status: Implementing in C++ for integration into the framework; 80% implemented

Pre/Post Processing

- Most techniques require a binary image, need a more sophisticated shape extraction routine than global thesholding
  - Need to investigate local thresholding as well as ridge-finding techniques
- After skeleton/centerlines are found, need to agglomerate segments into tracks and cluster tracks associated with showers
- At each vertex found, search local neighborhood for the best vertex position and track angles

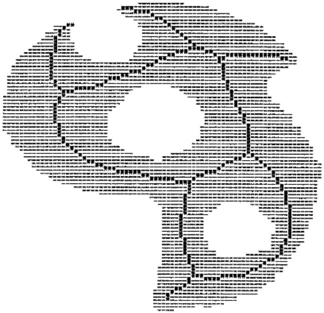
Voronoi Skeletons



- The Voronoi diagram of a set of points is the set of edges that are equidistant from from the two nearest points in the set
- The edges of the Voronoi diagram of the vertices of a polygon that are interior to the polygon compose the Voronoi skeleton
- Computationally intensive, would require a polygonal approximation to the boundary of a shape extracted from an image

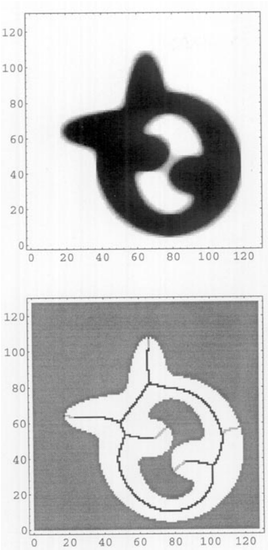
Skeletonization from Distance Transform

- C.W. Niblack, *et al.*, "Generating skeletons and centerlines from the medial axis transform ," Pattern Recognition, 1990. Proceedings., 10th International Conference on
- Fairly rudimentary algorithm that identifies extremal ridges in the distance transform and hill climbs from local extrema to the global maximum



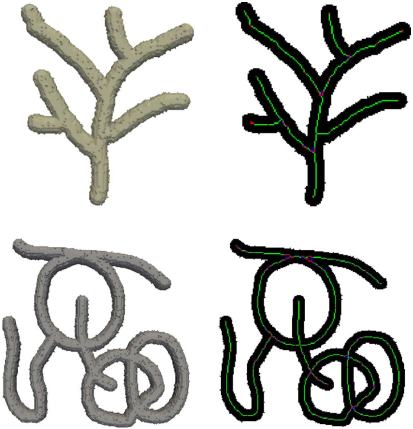
Skeletonization by Level Sets of Distance Map Differences

- R. Kimmel, *et al.* Skeletonization via distance maps and level sets. Comput. Vis. Image Underst. 62, 3 (Nov. 1995), 382-391.
- Segments the boundary of a shape at points of maximum curvature, computes the distance map from each segment, and finds the zero level sets of the difference between distance maps
- Author claims subpixel accuracy and insensitivy to image discretization, but makes heavy use of interpolations

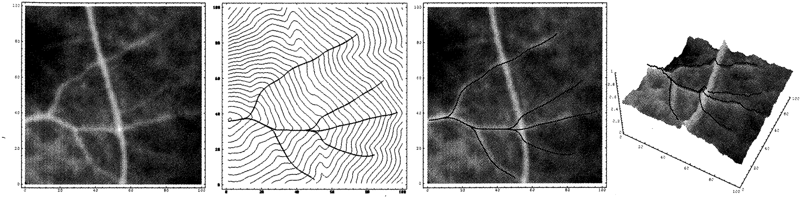


Flux-driven Centerline Extraction

- S. Bouix, *et al.* Flux driven automatic centerline extraction, Medical Image Analysis, Volume 9, Issue 3, June 2005, Pages 209-221
- Uses a property of the average outward flux of the gradient of the distance transform to find the centerline



Tracking By Intensity



- Track-like features can be traced by intensity
- Propagate a wave from a point known to be on a track at a speed given by the intensity then follow the gradient
- Avoids having to binarize the image
- R. Kimmel. Numerical Geometry of Images. Spring, 2003

Conclusion

- Techniques presented here are just a limited example of the field
  - http://www.visionbib.com/bibliography/contents.html provides a categorized libarary of computer vision papers
- Extracting geometry from images is a problem well explored; it's a matter of finding the appropriate techinques and adapting/tweaking them accordingly